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Assessing and measuring resilience

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Abstract

Concepts of resilience take two broad forms: (1) hard resilience : the direct strength of structures or institutions when placed under pressure , such as increasing the resilience of a structure through specific strengthening measures to reduce their probability of collapse. (b) soft resilience: the ability of systems to absorb and recover from the impact of disruptive events without fundamental changes in function or structure, which depend on the flexibility and adaptive capacity of the system as a whole, rather than simply strengthening structures or institutions in relation to specific stresses, as in the hard resilience approach. However, there are three possibilities in response to threats of disturbance: (a) Resistance and maintenance, which is characterized by resistance to change. A human system of this type would do its utmost to avoid change and would typically deny that a problem exists. (b) Change at the margins, characterized by acknowledgement of the problem, discussion of the implications, and, hopefully, a clear acknowledgement that the present system is not sustainable and that change is needed. (c) Openness and adaptability, an approach reduces vulnerability by having a high degree of flexibility. Its key characteristic is a preparedness to adopt new basic operating assumptions and institutional structures. Once the resilience options have been identified to meet the vulnerability of a system, it is necessary to compare the degree of resilience that the different alternatives may offer. The different concepts are examined to propose both a qualitative and a possible quantification of the degree of resilience that may be achieved by the different measures proposed for implementation.

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1. Resilience

1.1 Resilience of systems

Imagine a car going along a bumpy road. The passengers will feel the shocks, each time the car goes over a hump or on a pothole. However, if the car damping (shock absorbing) system is very good (or should we say efficient), the shocks will be barely noticeable, or even enjoyable for children as they slowly come back to their original position. Here, the car springs have the ability to absorb and recover from the impact of the shock of an uneven road surface.

This behaviour is in contrast to a boxer's practice sand bag, which barely moves under the boxer's fists hammering it, just as a brick wall will not move at all.

In each of the above examples, the system (car, sand bag, brick wall) has some characteristics which enable it to return (or to recover) to the original state. This is what is denoted by the resilience of a system. This is illustrated in Figure 1, which shows how a shock may affect a system's performance.

Thus, the concepts of resilience (Moench 2009) take two broad forms:

(a) hard resilience : the direct strength of structures or institutions when placed under pressure, such as increasing the resilience of a structure through specific strengthening measures to reduce their probability of collapse.

(b) soft resilience: the ability of systems to absorb and recover from the impact of disruptive events without fundamental changes in function or structure, which depend on the flexibility and adaptive capacity of the system as a whole, rather than simply strengthening structures or institutions in relation to specific stresses, as in the hard resilience approach.

1.2 Sectors needing resilience

A quick overview of resilience (Vale and Campanella 2005) may be obtained by examining a few cases of how existing infrastructure (roads, drains, buildings, hospitals, industry) behaves under disturbances, such as floods, hurricanes, earthquakes, economic crisis). Table 1 provides a list of infrastructure systems which affect everyday life. However, once the concept of resilience is understood, it can be observed that the concept may be extended to a variety of sectors, as shown in Figure 2.

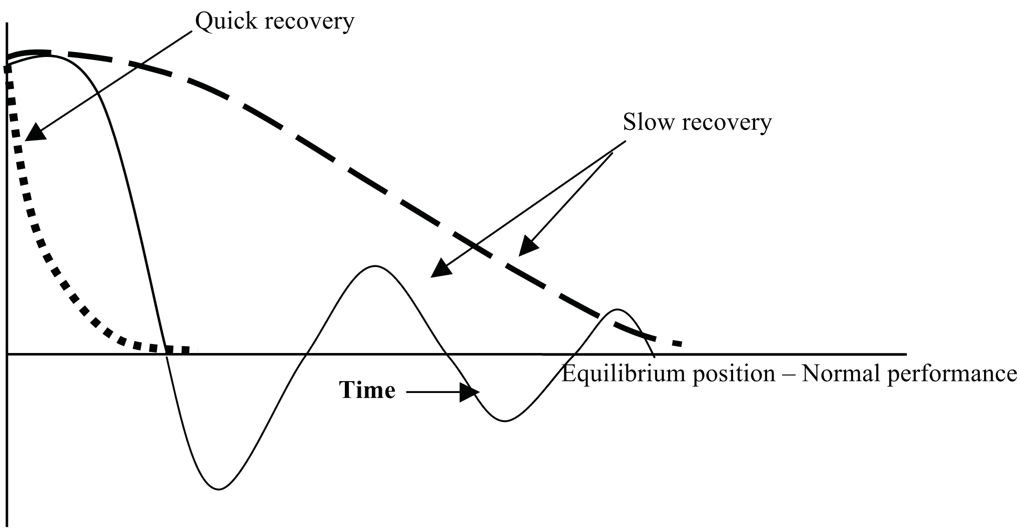

Figure 1. How a system returns to normal performance - equilibrium position

If the system behaves (Schipper and Burton 2009) in one of the ways illustrated in Figure 1, it is very likely because the system has been purposely designed to do so, and not just by chance. Generally speaking, whenever a possible disturbance is forecasted, there are three response possibilities (Handmer et Dovers 2009) to such threats:

1: Resistance and maintenance
This is characterized by resistance to change. A human system of this type would do its utmost to avoid change and would typically deny that a problem exists.
2: Change at the margins
This is characterized by acknowledgement of the problem, discussion of the implications, and, hopefully, a clear acknowledgement that the present system is not sustainable and that change is needed.
3: Openness and adaptability.
This approach reduces vulnerability by having a high degree of flexibility. Its key characteristic is a preparedness to adopt new basic operating assumptions and institutional structures.

Some of the reasons (Bruneau et al. 2003) behind such response lies partly in who makes cost/benefit decisions in a changing, competitive environment and who (taxpayers, private individuals, private enterprise) bears the cost of providing resilience. For example, faced with events that could destruct structures and harm employees, the benefits and costs of resilience must be evaluated from a holistic perspective so as to advise those concerned to make sound investment strategies. In particular, very few of the infrastructure of Table 1 can be said to be independent of the others, or in other words, would not affect others if it were itself disrupted during a disaster (Vugrin et al. 2010).

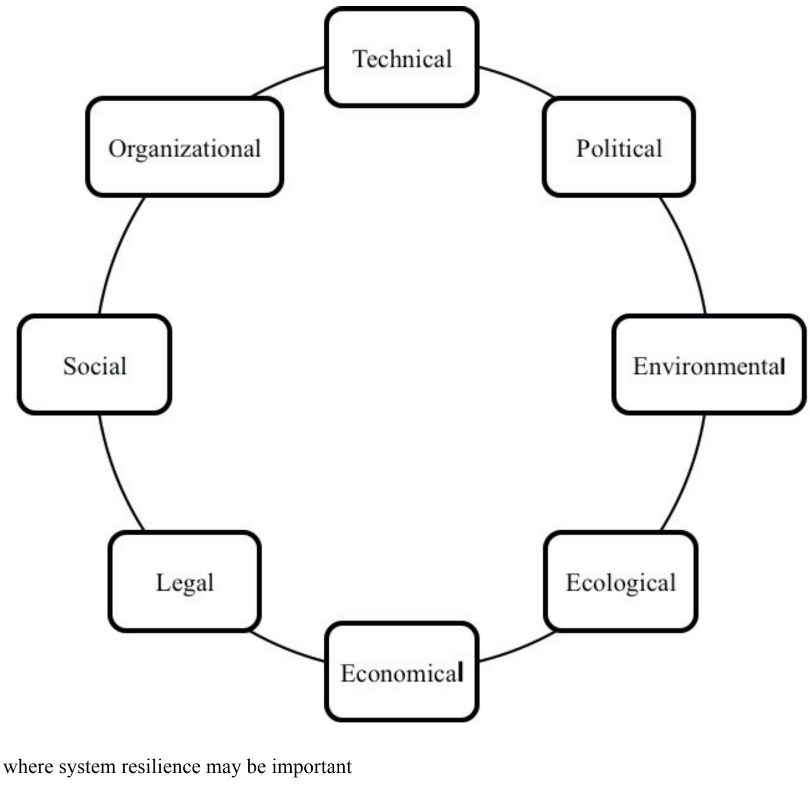

Figure 2. Sectors where system resilience may be important

It is, therefore, judicious to look critically at Infrastructure Resilience as an integrated goal of identifying the time required to restore full functionality.

Table 1: List of Infrastructure Assets

Sr. No	Infrastructure Asset	Sr. No.	Infrastructure Asset
1	Agriculture and Food	12	Government Facilities
2	Airport	13	Industrial Base
3	Banking	14	Information Technology
4	Chemical	15	Materials, and Waste
5	Commercial Facilities	16	National Monuments and Icons
6	Communications	17	Nuclear Reactors
7	Critical Manufacturing	18	Postal and Shipping
8	Dams, Emergency Services	19	Public Health and Healthcare
9	Defence	20	Seaport/Harbour
10	Drinking Water and Water Treatment	21	Transportation Systems
11	Energy		

1.3 Definition of resilience

A suitable definition of system resilience is as follows:

A system is usually designed to behave in a certain way under normal circumstances. When disturbed from equilibrium by a disruptive event, the performance of the system will deviate from its design level. The resilience of the system is its ability to reduce both the magnitude and duration of the deviation as efficiently as possible to its usual targeted system performance levels.

Figure 1, showing slow and quick recoveries, fully illustrates this definition.

System resilience will depend, at least, partly on inherent properties of – or those inbuilt in - the system. In particular, three such properties or capacities (Fiksel 2003; Rose 2005) are used to define, quantify, and design for better resilience:

(1) *absorptive capacity*, or the ability of the system to absorb the disruptive event;

(2) *adaptive capacity*, or the ability to adapt to the event; and

(3) *restorative capacity*, or the ability of the system to recover.

Table 2 explains the steps that can be carried out for assessing the resilience of social-economic systems (Resilience Alliance 2007a,b).

Table 3 lists some examples of performance which may be used as a measure for certain infrastructure and economic systems (Vugrin 2010).

Table 2: Assessing resilience of social-economic systems

Steps	Explanation
System definition	understand the components of the system and how resilience applies to the system
Identify critical resilient components	demarcate the boundaries of the system, identify appropriate scales to examine resilience, and identify the variables of concern
Identify sector resilience needed	identify external shocks and relevant internal parameters, through stakeholders and historical log
Identify stakeholders	identify the key players and the external critical parameters
Assess resilience	identify the recovery path and recovery efforts, through models
Management implications	inform policymakers/ managers how the system might react to shocks.
General assessment of resilience	synthesize the findings of the previous steps

Table 3 Possible performance metrics

Infrastructure System	System Performance Metrics
Agriculture and Food	Average food price, exposure to food contamination
Chemical	Pollution
Communications	Number of dropped telephone calls
Emergency Services	Lives saved; average response time
Energy:	Consumption, profitability of energy companies
Information Technology	Number of cyber attacks, internet access speed
Public Health and Healthcare:	Mortality rates, patient attendance
Transportation Systems: Highway	Average speed and cost of shipments; length of traffic jams

As is explained in a companion paper (Proag 2014), the absorptive, adaptation and restorative capacities of a system influence its resilience. Just as efficiency as the ratio of output to input, one can imagine defining a resilience efficiency as

$$\text{Resilience efficiency} = \frac{\text{Output under Shock}}{\text{Normal Output}}$$

Variations based on this will be discussed further down when dealing with quantitative assessment.

While output measures performance, it can be appreciated that the recovery time to normal performance can be another measure of resilience, as well as the effort required to do so.

A simple example: a damaged house does not offer the same facilities as before the disaster. How much time and effort (cost) does it take to get the house performing as before?

2. Qualitative Assessment

2.1 Risk analysis approach

Usually, in project management (Young 2003), a risk analysis is carried out prior to and during project implementation, as shown in Table 4. A complete brainstorming is carried out so as to collect the maximum sources of possible risks to the project.

Table 4. . Risk analysis

Risk approach	Activity carried out
Identification	Identify the source and type of risks
Classification	Consider the type of risk and its effect on the person or organisation
Analysis	Evaluate the consequences associated with the type of risk, or combination of risks, by using analytical techniques. Assess the impact of risk by using various risk measurement techniques
Attitude	Any decision about risk will be affected by the attitude of the person or organisation making the decision
Response	Consider how the risk should be managed by either transferring it to another party or retaining it.

Once a list of risks has been made, the assessing team decides, for each risk, (1) the probability of occurrence on a scale of 1 to 9 and (2) the impact on the project if it does happen. Thus each risk is classified as per Table 5.

Table 5. Risk probability and impact parameters

IMPACT ON THE PROJECT				
		LOW	MEDIUM	HIGH
Probability	7 - 9	Medium	High	Unacceptable
	4 - 6	Low	High	Unacceptable
	1 - 3	low	Medium	High

The details relating to the impact classification of Table 5 are explained in Table 6. These help in deciding what are the dangerous zones to avoid.

Table 6. Impact classification and related action

High	Major impact on the project schedule and costs. Serious consequent impact on other related projects. Likely to affect a project milestone. Must be monitored regularly and carefully
Medium	Significant impact on the project with possible impact on other projects. Not expected to affect a project milestone. Review at each project meeting and assess ranking. Monitor regularly.
Low	Not expected to have any serious impact on the project. Review regularly for ranking and monitor.

In a similar way, a qualitative resilience assessment can be carried out on the system under study.

Table 7. Qualitative assessment of system resilience under shock

Resilience assessment step	Activity carried out
Identified system and subsystem(s) of interest	System boundaries should be set so that the resilience assessment is of a manageable scope.
Identified system performance metric(s):	System performance metrics should be chosen that are most fundamental to the purpose the system from the perspective of the relevant stakeholders.
Assessed or simulated the recovery path	Identify the initial systemic impact as well as the changes in that impact over time as recovery proceeds.
Assessed or simulated the recovery effort	Because the recovery path is a function of the recovery effort, identifying both will likely follow similar qualitative or quantitative methods.
Identified resilience enhancement features and assessed resilience capacities	Identify features of their systems that affect resilience capacities.

Issues raised are ranked according to their impact and anticipated consequences by assigning a red, yellow or green flag. These determine the responsibility of those who need to pay particular attention, as given in Table 8.

Table 8 . Responsibility allocation for possible issues

Red flag	Major issue having serious consequences for the project. Prompt action needed to implement a decision to resolve. Overdue resolution of yellow flags.
Yellow flag	Significant impact on the project and/or other projects. Unless resolved promptly will cause delays to milestones. Becomes red if action delayed more than two days.
Green flag	Consequences limited to confined area of the project and unlikely to impact other projects. Becomes yellow if not resolved in time to avoid project slippage

3. Quantitative assessment

3.1 Resilience efficiency

While output measures performance, it can be appreciated that the recovery time to normal performance (Bruneau et al. 2003; Rose 2005) can be another measure of resilience, as well as the effort required to do so.

If we define the concept of Resilience efficiency = $\frac{\text{Output under Shock}}{\text{Normal Output}}$, it is logical to start working along these lines to introduce the recovery time and the effort required in an attempt to measure resilience.

3.2 Resilience quality

If two similar systems are equally damaged, the time it takes for them to recover back to normal performance can be a simple measure for resilience (cf. Figure 1). The longer time it takes, the less resilient it is.

However, during this recovery period, it may also be imagined that the system is partly functional, say y %. If this percentage is plotted during the recovery period, the area under this curve gives a measure of the product (performance x time). If there had been no damage, the area under this ciuve would have been 100 % x recovery period. Thus, the ratio of the former to the latter can give a quantitative measure of resilience that could be termed as resilience quality.

3.3 Effort (cost) resilience

Another measure (Rose 2007) that can be developed would rely on the effort (cost) (Y) required to build a new system. This can then be compared to the effort (cost) (X) required to recover to an equivalent system (as performing previously).

The effort (cost) resilience could then be expressed as effort (cost) resilience = (Y-X)/Y

This ratio would give 0 % if the whole system had to be rebuilt, and 100 % if no effort (cost) was required.

3.4 Comparison

It may be noticed that this last measure of resilience would still give 100 %, even if the system - though requiring no effort(cost) – takes a significant amount of time to recover to normal performance. It is therefore judicious to use several measures of resilience to compare or assess different systems.

4. Conclusion

Measuring resilience is not easy as this depends on the system under study. It is important to look at the ways resilience is being considered and use these as a method to measure resilience, either qualitatively and quantitatively.

In most cases, the systems are rarely totally down. While qualitative assessment is useful to understand how bad things are, quantitative measures give quantified estimates of performance, time and effort (cost) that are more meaningful to stakeholders.

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